FINAL DESIGN PROJECT REPORT

PRELIMINARY DESIGN OF TITANIUM DIOXIDE PLANT FROM ILMENITE CAPACITY OF 55,000 TONS/ YEAR

Submitted to Fulfillment the Bachelor's Degree in Chemical Engineering

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D 500 122 005

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UNIVERSITAS MUHAMMADIYAH SURAKARTA

2017

APPROVAL PAGE

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SCIENTIFIC PUBLICATIONS

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Abstrak

Titanium dioksida merupakan senyawa anorganik dengan rumus kimia TiO_2. Pabrik titanium dioksida dirancang dengan kapasitas 55,000 ton/ tahun. Pabrik ini direncanakan beroperasi selama 330 hari per tahun. Titanium dioksida akan dibangun pada tahun 2020 di Belitung Timur, Bangka Belitung. Titanium dioksida digunakan sebagai pigmen putih (dalam cat, plastik, karet dan kertas), industri keramik, serat, dan kosmetik, juga digunakan sebagai katalis dan fotokatalis. Produk dari titanium dioksida rencananya akan didistribusikan untuk kebutuhan dalam negeri. Proses pembuatan titanium dioksida dilakukan dengan mereaksikan ilmenit dengan gas klorin menghasilkan $TiCl_4$ dengan menggunakan kokas sebagai agen pereduksi dalam reaktor *fluidized bed* fase gas-padat. Proses berlangsung pada suhu 900°C dan tekanan 1 atm. Keluaran dari Reaktor 1 dimurnikan dan diumpankan ke Reaktor *Fluidized Bed* 2 yang beroperasi pada suhu 1000°C dan tekanan 1 atm dalam reaksi bolak-balik dan eksotermis. Pabrik ini diklasifikasikan sebagai pabrik beresiko tinggi. Kebutuhan bahan baku ilmenit sebesar 18,314.8573 kg/h, klorin sebesar 4,578.7143 kg/h, dan kokas sebesar 16,255.0694 kg/h. Utilitas termasuk pendukung proses dengan kebutuhan air total sebesar for 26,733.6942 kg/hour diperoleh dari air sungai. Kebutuhan dowtherm sebesar 124,312.4091 kg/h. Kebutuhan bahan bakar minyak sebesar 2.3222 m^3/hour. Kebutuhan udara tekan sebesar 122 m^3/h. Kebutuhan listrik dipenuhi dari PLN dan generator sebagai cadangan tenaga sebesar 986.4136 kW, bahan bakar sebesar 9.2860 m^3/h. Total luas tanah adalah 19,770 m^2. Ketersediaan bahan baku ilmenit diperoleh dari PT. Timah Tbk dan gas klorin diimpor dari luar negeri. Jumlah karyawan sebanyak 201 orang.Pabrik titanium dioksida membutuhkan Rp588,594,482,703 sebagai modal tetap dan Rp320,860,312,440 sebagai modal kerja. Berdasarkan analisis ekonomi, pabrik ini akan mendapatkan keuntungan sebelum pajak sebesar Rp400,433,669,735 per tahun dan keuntungan setelah 30% pajak sebesar Rp120,130,100,920. Jumlah persen *dari Return of Investment* (ROI) sebelum pajak dan sesudah pajak adalah 68% dan 47% berturut-turut. *Pay Out Time* (POT) sebelum pajak dan sesudah pajak sekitar 1.28 tahun dan 1.74 tahun. *Break Even Point* (BEP) adalah 46% dan *Shut Down Point* adalah 56%. *Internal Rate of Return* (IRR) adalah 56%. Berdasarkan dari kelayakan ekonomi, maka dapat disimpulkan bahwa pabrik titanium dioksida layak untuk didirikan.

Kata kunci: Titanium dioksida, Ilmenit, Reaktor *Fluidized Bed*

Abstract

Titanium dioxide is an inorganic compound with chemical formula TiO_2. Titanium dioxide plant is designed with capacity of 55,000 tons per year. The plant is planned to operate for 330 days per year. Titanium dioxide will be built in 2020 on East Belitung, Bangka Belitung. Titanium dioxide is used as a white pigment (in paints, plastics, rubber, and paper), industry of ceramics, fiber, and cosmetics, also used as catalysts and photocatalysts. The product of titanium dioxide is planned to be distributed for domestic needs. Titanium dioxide-making process is done by reacting ilmenite with chlorine gas that produce $TiCl_4$ using coke as reducing agent in a first fluidized bed reactor solid-gas phase. The process takes place at a temperature of 900°C and a pressure of 1 atm. The output of first Reactor is purified and fed to second Fluidized Bed Reactor that continuously operates at a temperature 1000°C and a pressure of 1 atm. The processes are irreversible reaction and exothermic. This plant is classified as high risk plant. The need for raw materials ilmenite is 18,314.8573 kg/h, chlorine is 4,578.7143 kg/h, and coke is 16,255.0694 kg/h. Utilities include water supply process support for 26,733.6942 kg/hour is obtained from river water. Dowtherm supply is 124,312.4091 kg/h. Diesel fuel is 2.3222 m^3/hour. Compressed air requirement is 122 m^3/h. Electricity demand is obtained from the PLN and generator for backup power is 986.4136 kW, fuel is 9.2860 m^3/h. Total land area is 19,770 m^2. The availability of raw material of ilmenite is obtained from PT. Timah Tbk. and chlorine gas is imported from abroad. The number of employees is 201 people.The titanium dioxide plant needs 588,594,482,703 IDR of fixed capital. Titanium dioxide needs 320,860,312,440 IDR of working capital. Based on the economic analysis, the plant will get 400,433,669,735 IDR of profit before tax. The plant will get 120,130,100,920 IDR of profit after 30% of tax per year. Number of percent Return of Investment (ROI) before tax and after tax is 68% and 47%, respectively. Pay out Time (POT) before tax and after tax is about 1.28 years and 1.74 years, respectively. Break Even Point (BEP) is 46% and shut down point is 35%. Discounted cash flow (DCF) is 56%. Based on the economic feasibility, it can be concluded that the titanium dioxide plant is considered feasible to be built.

Keyword: Titanium dioxide, Ilmenite, Fluidized Bed Reactor

1. INTRODUCTION

1.1. Background

In the industrial and free trade era, it is necessary to set up an industry that can provide great benefit to the development of industry in Indonesia. One type of these industries include industrial of titanium dioxide (TiO_2). Based on statistical data, Indonesia is still importing titanium dioxide from China, Australia, Japan, USA, etc (BPS, 2015).

It is the brightest white pigment with the highest opacity of any commercial product, and is used to impart whiteness and opacity to paints, plastics, paper and in many other smaller applications. TiO_2 can also improve the durability of coatings, paper laminate and plastic items. Because of its clean tone and opacifying properties, TiO_2 is widely used in pastel and colored finishes as well as whites. Around 60% is used in paints or coatings, 20% in plastics, 12% in paper and 8% in a wide range of smaller applications (Cristal, 2016).

1.2. Design Capacity

Titanium dioxide import developments in Indonesia can be seen in Table 1.2 below.

Table 1.2 Data of Titanium Dioxide Import in 2011-2014 (BPS, 2015)

Years	Consumption (tons)
2011	46,706.1100
2012	51,581.2400
2013	50,381.6330
2014	53,456.7600

From the results of data processing and review of titanium dioxide production capacity of the plant that has been operating and market absorption capability, so it will be built the titanium dioxide plant using the chloride process with a capacity of 55,000 tons/ year and the plant will start operating in 2020.

2. METHODOLOGY

2.1. PROCESS SELECTION

There are two processes of titanium dioxide manufacturer, namely:

a. Chloride Process

The chloride process begins with the conversion of high-grade ilmenite into titanium tetrachloride. This step occurs in a fluidized bed chlorinator in the presence of chlorine gas at a temperature of approximately 900°C. Coke also is added as a reductant. The gaseous product stream is purified to separate the titanium tetrachloride from other metal chloride impurities using condensation. The purified $TiCl_4$ is then oxidized to TiO_2.

b. Sulfate Process

The sulfate process starts with dried and milled slag TiO_2 being dissolved in sulfuric acid and water in a digester. This produces a titanyl sulfate liquor. The titanium liquor then is concentrated and hydrolyzed to titanium dioxide hydrate.

Based on the above process, titanium dioxide plant will use the chloride process for titanium dioxide which would be produced in the form of rutile. The considerations of the chloride process selection are:

1. Titanium dioxide is main product.
2. No form waste in large quantities
3. Produce titanium dioxide high quality of rutile. Rutile is the most stable oxide titania.

2.2. THE USE OF THE PRODUCT

Titanium dioxide is used as a white pigment (in paints, plastics, rubber, and paper), industrial ceramics, fiber, cosmetics, and also used as catalysts and photocatalysts.

2.3. PLANT LOCATION

The plant will be built in East Belitung Area, Bangka Belitung. The factors that influence in considerations of plant location in Belitung Island are directly affect the main production which is near the raw materials and easy of the distribution of the products.

2.4. THE STEPS OF THE PROCESS

Production process of titanium dioxide through three process units, raw materials preparation and storage unit, product formation unit, and finishing unit.

a. Raw Materials Preparation and Storage Unit

Raw material of chlorine (Cl_2) is stored in cylindrical tank (F-112) with operating condition at temperature 30˚C and pressure 9 atm in liquid phase with the aims to minimize volume of tank used. Chlorine gas used is high purity of chlorine as much as 99.99%. The aims of using chlorine with high purity to maintain the high purity of titanium dioxide product. Then, chlorine gas is passed into valve and change into gas phase then pressed until the pressure 1.2 atm as feed of Reactor (R-100).

Raw material of ilmenite obtained from residue of tin mining of PT. Timah Tbk., ilmenite is stored in storehouse at operating condition with temperature 30˚C and pressure 1 atm, then messed using Ball Mill (C-114) until the size is 149 μm, then ilmenite by Screw Conveyor (J-115) distributed as Reactor feed (R-100).

Air is taken from surrounding environment with the operating condition at temperature 30˚C and pressure 1 atm the pressed until 1.2 atm using Blower (G-118) then is fed to the Reactor (R-100).

b. Product Formation Unit

Titanium dioxide is produced from reaction between titanium dioxide ore in ilmenite with chlorine gas in reactor of $TiCl_4$ formation with type of Fluidized Bed Reactor (R-100) at temperature around 900˚C and pressure 1 atm by adding the coke as reductant.

$FeCl_3$ formed from Fe_2O_3 contained in ilmenite. Chloride non-volatile, residual coke, and the unreacted impurities of ilmenite ore are removed from the gas stream and from the bottom of the Chlorinator (R-100) into Grate Cooler (E-121) to be cooled until ambient temperature and input to the waste management unit. Gas main stream products exit from reactor (R-100) then cooled in cooler (E-122) - (E-124) using dowtherm until temperature 420˚C. Gas stream products have been cooled then purified to separate $TiCl_4$ from other gas through condensation, so that product input to the partial condenser (E-216) cooled until temperature reach 170˚C where $FeCl_3$ will be condensed then cooled back until temperature reach 40˚C, then input to the partial condenser (E-315) the cooled until temperature 53.54˚C, and $TiCl_4$ will be condensed. Exhaust gas in the form of CO, N_2, and Cl_2 taken to the Absorber (D-300), where

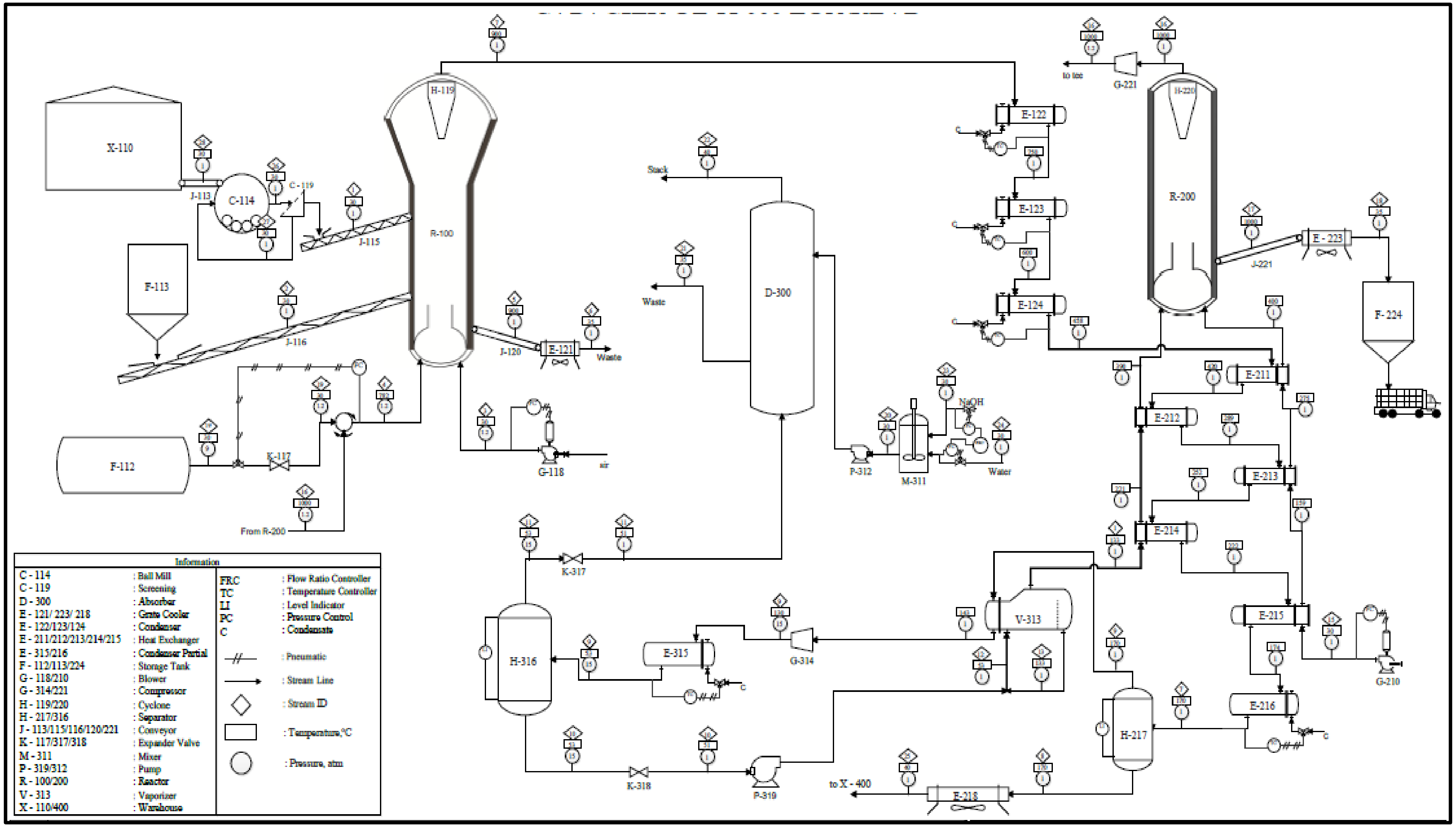
Cl_2 reacted with NaOH produced $NaCl$, $NaOCl$, and H_2O. Then $NaCl$, $NaOCl$, and H_2O sent to the waste management unit. Besides, CO, N_2, $TiCl_4$ and $FeCl_3$ is separated then input to the waste management to be burned in the stack.

The purified $TiCl_4$ that have been condensed input to the Vaporizer (V-313) to be vaporized, then fed into oxidation reactor with type Fluidized Bed Reactor (R-200). In the reactor, gas phase of $TiCl_4$ then through oxidation reactions with oxygen at temperature 1000˚C and atmospheric pressure to form the titanium dioxide and chlorine gas.

The stream that contain chlorine gas, little bit of $TiCl_4$ and other gas are recycled joining with chlorine gas as feed of R-100. The pure TiO_2 is slurred and sent to finishing process.

c. Finishing Unit

Titanium dioxide exit from Reactor (R-200) then cooled in Grate Cooler (E-223) until temperature 40˚C, then is stored in Silo (F-224).


X-110
J-113
C-114
C-119
J-115
F-113
J-116
F-112
K-117
From R-200
H-119
R-100
J-120
E-121
Waste
G-118
air
Stack
Waste
D-300
NaOH
P-312
M-311
Water
K-317
H-316
E-315
G-314
K-318
P-319
to X - 400
E-218
to tee
G-221
H-220
R-200
E-122
E-123
E-124
J-221
E - 223
F- 224
E-211
E-212
E-213
E-214
V-313
E-215
G-210
E-216
H-217
Information
C - 114 : Ball Mill
C - 119 : Screening
D - 300 : Absorber
E - 121/ 223/ 218 : Grate Cooler
E - 122/123/124 : Condenser
E - 211/212/213/214/215 : Heat Exchanger
E - 315/216 : Condenser Partial
F - 112/113/224 : Storage Tank
G - 118/210 : Blower
G - 314/221 : Compressor
H - 119/220 : Cyclone
H - 217/316 : Separator
J - 113/115/116/120/221 : Conveyor
K - 117/317/318 : Expander Valve
M - 311 : Mixer
P - 319/312 : Pump
R - 100/200 : Reactor
V - 313 : Vaporizer
X - 110/400 : Warehouse
FRC : Flow Ratio Controller
TC : Temperature Controller
LI : Level Indicator
PC : Pressure Control
C : Condensate
: Pneumatic
: Stream Line
: Stream ID
: Temperature,°C
: Pressure, atm

2.5. THE CONCEPT OF THE PROCESS

a. Basic of Reaction

Titanium dioxide is formed from mineral of ilmenite and chloride gas follows the reaction:

$$TiO_2 + 2Cl_2 + 2CO \longrightarrow TiCl_4 + 2CO_2 \qquad (2\text{-}1)$$

$$TiCl_4 + O_2 \longrightarrow TiO_2 + 2Cl_2 \qquad (2\text{-}2)$$

b. Kinetic Review

Formation reaction of titanium dioxide from ilmenite goes through several steps of reactions:

1. Combustion reaction of coke using air. The reaction equation as follows:

$$C + \tfrac{1}{2}O_2 \longrightarrow CO \qquad (2\text{-}3)$$

Reaction constant k that influenced by an Arrhenius equation as follows (Hughes, 1971):

$$k = \frac{1.914\ x\ 10^8}{0.5} exp\left(\frac{-156200}{RT}\right) \qquad (2\text{-}4)$$

Where k is the rate coefficient (s^{-1}), R is gas constant (8.314 J/mol.K) and T is temperature (K).

2. Reaction of ilmenite with Cl_2 and outlet gas of coke combustion. The equation reaction as follows:

$$TiO_2 + 2Cl_2 + 2CO \longrightarrow TiCl_4 + 2CO_2 \qquad (2\text{-}5)$$

$$Fe_2O_3 + 3Cl_2 + 3CO \longrightarrow 2FeCl_3 + 3CO_2 \qquad (2\text{-}6)$$

The chlorination rate and time (Li-Ping, 2013):

$$\frac{R}{3k_g} + \frac{r_o}{2D_e} + \left[1-(1-R)^{\frac{2}{3}} - \frac{2}{3}R\right] + \frac{1}{k_r}\left[1-(1-R)^{\frac{1}{3}}\right] = \frac{bc}{r_o\,\rho_s}t \qquad (2\text{-}7)$$

Where:

R = Reaction rate;

k_g = Gas film mass transfer coefficient;

k_r = Rate constant of interfacial reaction;

r_o = Radius of particles;

D_e = Effective diffusivity of Cl_2 in TiO_2 particle;

ρ_s = Density of fluidized particle;

t = Time

b = 538

c = 11873

3. The formation of TiO_2 takes place by the overall reaction of $TiCl_4$ with O_2

$$TiCl_4 + O_2 \longrightarrow TiO_2 + 2Cl_2 \quad (2\text{-}8)$$

The depletion of $TiCl_4$ rate can be calculated by the equation 2-9 (Spicer, 2002):

$$k = 8.26\ x\ 10^4 \exp\left(\frac{-10{,}681}{T}\right) \quad (2\text{-}9)$$

Where T (K) is the process temperature and k is the overall oxidation rate constant of $TiCl_4$, s^{-1}).

c. Thermodynamic Review

The goal of thermodynamics review is to know the reaction characteristic (endothermic/ exothermic) and directions of the reaction (reversible/ irreversible).

Reaction in Chlorinator:

$\Delta H_{reaction\ 298\ K} = \Sigma\ \Delta H_{f\ product} - \Sigma\ \Delta H_{f\ reactant}$

$= (1.\Delta H^{\circ}_f TiCl_4 + 2.\Delta H^{\circ}_f CO_2) - (1.\Delta H^{\circ}_f TiO_2 + 2.\Delta H^{\circ}_f Cl_2 + 2.\Delta H^{\circ}_f CO)$

= -384.46 kJ/ mol (exothermic)

Reaction in Burner:

$\Delta H_{reaction\ 298\ K} = \Sigma\ \Delta H_{f\ product} - \Sigma\ \Delta H_{f\ reactant}$

$= (1.\Delta H^{\circ}_f TiO_2 + 2.\Delta H^{\circ}_f Cl_2) - (1.\Delta H^{\circ}_f TiCl_4 + 1.\Delta H^{\circ}_f O_2)$

= -181.5 kJ/ mol (exothermic)

Reaction in Chlorinator:

$\Delta G_{reaction\ 298\ K} = \Sigma\ \Delta G_{product} - \Sigma\ \Delta G_{reactant}$

= -351.96 kJ/ mol

Reaction in Burner:

$\Delta G_{reaction\ 298\ K} = \Sigma\ \Delta G_{product} - \Sigma\ \Delta G_{reactant}$

= -162.5 kJ/ mol

Equilibrium constant at temperature 25˚C (298 K)

Reaction in Chlorinator:

$\Delta G_{298\,K} = -R.T\ ln\ K$ (2-10)

Where:

R = 8.314 J/ mol.K

T = Temperature (K)

K = equilibrium constant

$ln\ K$ = 197.4191

K = 5.4704 x 10^{85}

Equilibrium constant at temperature 900˚C (1173 K)

$$\frac{ln\,K_{1173}}{ln\,K_{298}} = -\frac{\Delta H}{R}\left(\frac{1}{T_2} - \frac{1}{T_1}\right) \quad (2\text{-}11)$$

$ln\ K_{1173}$ = 632.5497

K = 5.1621 x 10^{274}

Reaction in Burner:

$\Delta G_{298\,K}$ = $-R.T\ ln\ K$ (2-12)

$ln\ K$ = 65.5884

K = 3.0527 x 10^{28}

Equilibrium constant at temperature 1000˚C (1273 K)

$$\frac{\ln K_{1273}}{\ln K_{298}} = -\frac{\Delta H}{R}\left(\frac{1}{T_2} - \frac{1}{T_1}\right) \quad (2\text{-}13)$$

$ln\ K_{1273}$ = 210.1515

K = 1.8521 x 10^{91}

The value of K is very high so that the reaction is irreversible.

3. RESULT AND DISCUSSION

3.1. Reactor – 01

Code	: R-100
Function	: The place for reacting of coke with hot air to form CO gas that reacts with ilmenite to form $TiCl_4$ gas
Amount	: 1
Type	: Fluidized Bed Chlorinator
Material	: Carbon Steel 212 Grade C + Firebrick
Cost	: 997,536.95 USD

Operating Conditions

Temperature, ℃	: 900
Pressure, atm	: 1
Diameter of Reactor, m	: 7.4748
Total Height of Reactor, m	: 33.2037
Distribution Plate	: 567

3.2. Reactor – 02

Code	: R-200
Function	: The place for the reaction $TiCl_4$ with hot air to produced TiO_2
Amount	: 1
Type	: Fluidized Bed Chlorinator
Material	: Carbon Steel 212 Grade C + Firebrick
Cost	: 775,862.07 USD
Operating Conditions	
Temperature, ℃	: 1000
Pressure, atm	: 1
Diameter of Reactor, m	: 3.7583
Total Height of Reactor, m	: 25.4120
Distribution Plate	: 1127

3.3. Utility

Process supporting unit is often called the utility unit that is an important part to support the production process in the plant. Process supporting unit contained within the plant of titanium dioxide are:

1. Water Supply Unit
   Water supply unit aims to provide water to be used as process water, cooling water, water consumption and sanitation.
2. Dowtherm Supply Unit
   Dowtherm supply unit aims to provide coolant to be used as cooling process.

3. Electricity Supply Unit

   This unit to fulfill the electricity needs for titanium dioxide plant.

4. Fuel Supply Unit

   This unit is used to supply the fuel of generator.

5. Compressed Air Supply Unit

   Compressed air is used to operate the instrumentation system.

6. Waste Treatment Unit

   Waste generated from titanium dioxide plant to be processed prior to waste treatment unit before being discharged into the environment.

7. Laboratory

   Laboratory is a very important part in supporting a smooth production process and maintain product quality.

3.4. Plant Management

Form	: Limited Liability Company (PT)
Business Field	: Titanium Dioxide Industry
Location	: East Belitung

Consideration of the selection of companies based on several factors, are:

1. Regulated law and easy to get capitals by selling shares of the company.
2. The responsibility of shareholder is limited, so that the fluency production is only held by the company.
3. The owners and executives of companies apart from one another, the owner of the company is the shareholder and management of the company is the directors and its staffs are supervised by commissioners.
4. Continuity of the company is more secure because it does not affect the cessation of shareholder, directors or employees of the company and its staff and the efficiency of management and business field broader.

3.5. Economic Anaysis

Economic analysis is useful to determine whether the plant to be established can be profitable or not and feasible or not. The most important of design plant is estimation of equipment cost because equipment cost is used as basic for capital investment feasibility in production of a plant by review needs of Rate of Investment (ROI), profit, and Pay Out Time (POT), and Break Even Point (BEP).

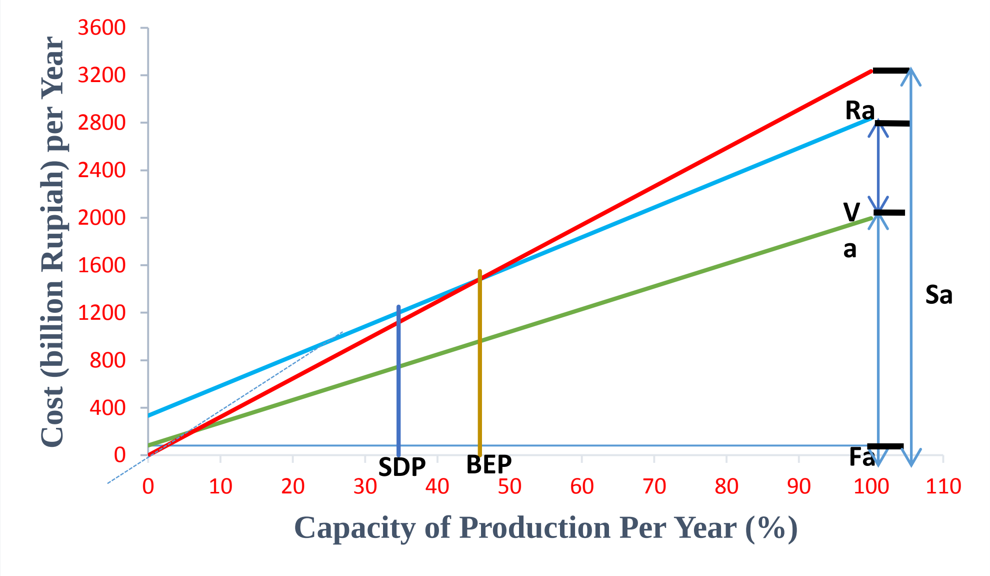


Figure 1 Economic Analysis

4. CONCLUSION

The result of the economic analysis feasibility as a follows:

1. Profit before tax is 400,433,669,735.39IDR per year.

   Profit after tax is 280,303,568,814 IDR per year.

2. ROI (Return on Investment) before tax is 68%.

   ROI after tax is 47%.

3. POT (Pay Out Time) before tax is 1.28 years.

   POT after tax 1.74 years.

4. BEP (Break Even Point) is 46% and SDP (Shut Down Point) is 35%.

   BEP for common chemical plant is around 40 – 60%.

5. IRR (Internal Rate Return) is 56%.

Titanium dioxide plant with chloride process is designed with a capacity of 55,000 tons/ year. The plant is classified as high risk plant operates at temperature 900–1000˚C and pressure 1 atm. Based on the economic feasibility, it can be concluded that the titanium dioxide plant is considered feasible to be built.

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